Accelerator-Driven System and Light Water Reactors with Inert Matrix Fuel for Removal of Plutonium and Minor Actinides in the Spent Fuel

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1. Introduction

Plutonium (Pu) and minor actinides (MA) are particularly toxic and long-lived elements in the nuclear spent fuel and can survive up to even hundreds of thousands years. Accelerator-driven system (ADS) [1-4] is widely considered as a promising reactor tool for burning Pu and MAs through transmutation of those elements to less toxic and short lived elements. A critical fast reactor can also perform transmutation. But, as ADS has neutrons supplied from an external source (accelerator) and these are actually delayed neutrons. ADS has larger safety margin, which means distance from the prompt criticality than critical reactors as shown in Fig. 1, and more importantly, this feature (more delayed neutrons) allows Pu and MA alone to be used as fuel with no U-238 matrix. As both Pu and MAs emit small number of delayed neutrons, the U-238 matrix supplies sufficient delayed neutrons for safe control of a critical reactor. Hence, a critical reactor is technically difficult to operate with a fuel made of only Pu and MA without U-238 because of narrow safety margin. If U-238 is added to increase the safety margin, U-238 is converted to Pu through neutron capture. This is why ADS is safer and more efficient in transmutation of Pu and MA than a critical fast reactor.

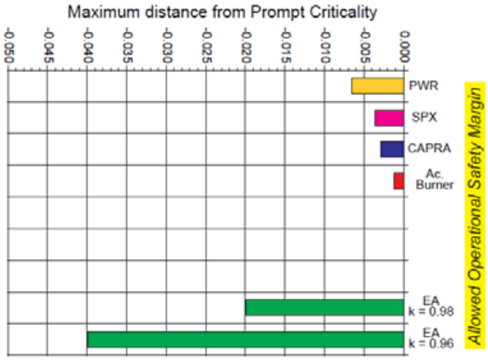

Fig. 1. Safety margin of a few types of nuclear reactors.

ADS needs reprocessing of the spent fuel to separate Pu and MA. However, Korea may use only the pyro-processing in which Pu and MA are not differentiated. But, it is the best to be able to use Pu and MA separately for effective ADS plan as can be seen in the example of JAEA ADS of Japan shown in Fig. 2. In the conceptual design of JAEA ADS [5], the fuel is made of 60% MA + 40 % Pu. In this plan, Pu is regarded as a fuel while MA is regarded the as transmutation target with the transmutation rate of 10 units of LWR. However, in any possible ADS plans of Korea, both Pu and MA should be regarded as transmutation targets and used in the mixed state.

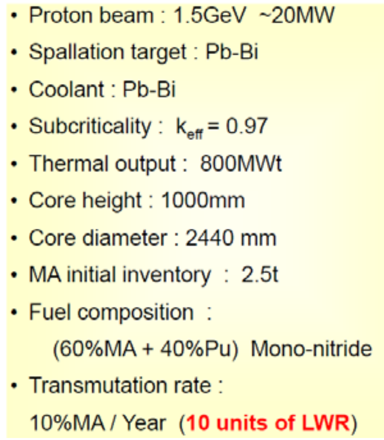

Fig. 2. Conceptual design of JAEA ADS.

To be able to separate Pu and MA effectively in the context of pyro-processing, this paper suggests use of the inertial matrix fuel (IMF) in the light water reactors (LWR) [6-12]. IMF is a type of nuclear reactor fuel that consists of a neutron-transparent matrix, instead of the conventional U-238 matrix, and a fissile phase (Pu in this case) that is either dissolved in the matrix or incorporated as macroscopic inclusions. The matrix dilutes the fissile phase to the volumetric concentrations as required by reactor control, which is the same role U-238 plays in the more conventional fuel types including the mixed oxide (MOX) fuel. The difference is that replacing fertile U-238 with a neutron transparent matrix does not make plutonium breeding. IMF is a powerful tool to burn Pu safely in a conventional LWR without conversion from U-238 to plutonium as can be seen in Fig. 3.

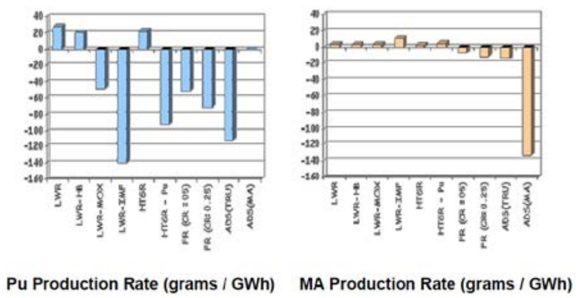

Fig. 3. Pu production rate and MA production rate of several nuclear reactors [13]. Negative numbers mean burning.

Similarly, Fig. 3 shows that ADS is a powerful tool of burning MA. Therefore, it was previously presented that combined use of the accelerator-driven system (ADS) and the IMF loaded LWR is the best way in Korea to burn both plutonium and minor actinides contained in the nuclear spent fuel in the safety, burn-efficiency and cost effectiveness [14]. More details are given in this presentation.

2. Combined use of ADS and IMF for burning Pu and MAs

A spent fuel composition is shown in Fig. 3. Therefore, Pu + MA, where Pu is dominant over MA in the 9 : 1 ratio as unloaded from a pyro-processing unit, may thus be practically regarded as Pu and is defined as X. X should be burned deeply (deep-burn) in a conventional LWR loaded with IMF. The waste Y = Pu + MA collected from several LWRs after multi-recycling may be practically regarded as MA because Pu occupies only a small part of Y. Y should be put into a transmutation-dedicated ADS system as shown in Fig. 5.

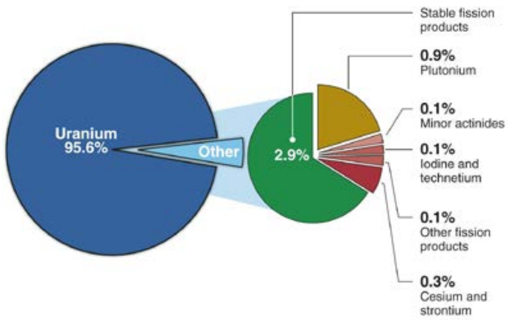

Fig. 4. Spent fuel composition. Pu occupies 0.9% and MA occupies 0.1% of the whole spent fuel.

Therefore, with the combined use of ADS and IMF, X can be regarded as Pu and Y can be regarded as MA. Hence, the 60% Pu + 40% MA fuel of JAEA in Fig. 2 can be practically prepared by 60% X + 40% Y, and the same level of transmutation rate can be achieved. This way, any composition of ADS fuel can be practically prepared with X and Y.

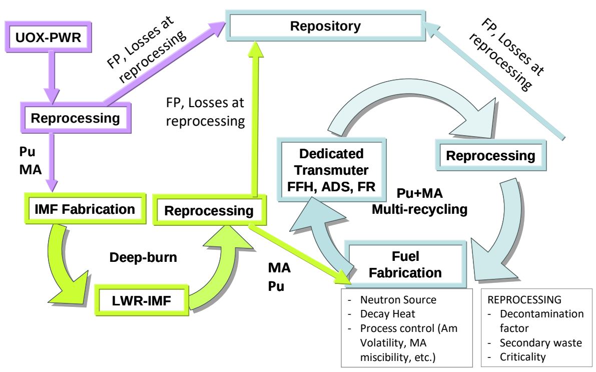

Fig. 5. Schematic figure of deep-burn first and transmutation-dedicated ADS [15].

Based on the JAEA design, two units of ADS may be able to burn almost all MA produced every year in Korea. However, the key problem is that both ADS and IMF are not developed yet for immediate use. Unlike IMF that can be used for a typical LWR, ADS is more costly to build mainly because of the required high energy and high power external proton accelerator. Accurate cost estimation of the accelerator is not easy but loose estimation gives about 20% construction cost of the reactor itself.

3. Conclusion

Figure 3 shows that the LWR-IMF combination may be the best choice for Pu-burning while ADS is the most efficient for MA transmutation. With the pyro-processing scheme in which Pu and MA are not differentiated, the LWR-IMF and ADS combination can still work properly by using X and Y instead of Pu and MA.

Therefore, a good scenario for Korea is to (1) load IMF containing X from reprocessed spent fuel into several LWRs, (2) deep-burn Pu and multi-recycle the spent fuel, and (3) transmute the final waste Y in an ADS.

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